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Radiological Defense, Vol. IV

RADIAC

An Introduction to Radiological Instruments for Military Use

by

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FOREWORD

This volume is the fourth of a series of Radiological Defense Manuals issued by the Armed Forces Special Weapons Project for training purposes in the Department of Defense. The objective of Volume IV is to present certain phases of the radiological instrumentation program in such form as to assist defense personnel in preparing themselves for the complex detection problem which must be faced during atomic warfare.

Aspects of the program are presented as seen today. It is anticipated that research and development now under way will make many of the instruments herein described obsolete within a period of 18 months.

The volume combines with the description of specific instruments a basic consideration of the mechanism of radiation detection and an indication of possible operational use, so that field personnel may be given a comprehensive picture of the role to be played by radiological instrumentation during atomic warfare.

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RADIATION INSTRUMENTS FOR MILITARY USE

Chapter 1

INTRODUCTION

The development of the atomic bomb and the possible development of radiological warfare agents require that future military plans contain a certain emphasis on radiological defense. Instruments are a basic requirement in any such defense plan, since nature has not equipped man with senses capable of responding to nuclear radiations. Irreparable damage may be produced in high intensity fields which cannot be recognized without the use of suitable instruments.

Since the first atomic bomb explosion, increasing emphasis and thought have been placed upon the development of instruments suitable for military use. The instrumentation requirements are in many respects similar to those which have been encountered in X-ray radiographic and therapeutic use, radium radiographic and therapeutic use, isotope research and therapeutic use, cosmic ray research, and investigations with high energy accelerators. Military instruments in general require, in addition, an ability to withstand rough usage under extreme weather, temperature, and geographic conditions. They should also be made as simple and foolproof as is possible within the limits of their detecting requirement.

The field of radiological instrumentation, as it applies to the defense establishment, has been assigned the name "RADIAC". This new word for the military vocabulary has been taken from the initial letters of—RAdiation, Detection, Indication, And Computation.

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Chapter 2

RADIATION IN GENERAL

2.01 Introduction

Radiation, in the sense in which we are concerned, means nuclear emissions and is not concerned with the radiations which are manifest as radio waves, heat, and light (1) (2).* It is possible to separate these nuclear emissions into electrically charged and electrically neutral categories.

The electrically charged radiation consists of particles in motion such as:

beta (β) particles (electrons—e^-)
alpha (α) particles (helium nuclei—He^{++})
protons (p) (hydrogen nuclei) (no military importance)
positron (positive electron) (no military importance)

The electrically neutral radiation consists of:

neutron (n)
gamma rays (γ)
X-rays (not considered as a nuclear radiation)

Except in a few unique applications, military consideration is given to the measurement of the charged alpha and beta particles and to the electrically neutral gamma rays. Of these radiations, the greatest emphasis is placed on measurement of gamma rays. Table I gives some rough comparisons of the characteristics of alpha and beta particles and gamma rays.

The measurement of neutrons will become important in conjunction with the operation of nuclear reactors for power production or the propulsion of ships or aircraft. Detection of neutrons involves some specialized applications of the detecting principles which will be discussed. However, a detailed description of neutron detection will be omitted, since neutrons at present are of limited interest to the Defense Establishment.

It should be noted that there are certain elements which give off pure alpha and pure beta radiations. Gamma radiations are produced only as an after-effect of either an alpha or a beta emission. With very minor exceptions, there is no such thing as a pure gamma emitter, although in some cases the alpha or beta emissions may be so weak as to be virtually indetectable.

TABLE I.—*Characteristics of nuclear radiation*

Radiation	Nature	Energy	Ionizing power in air	Penetration	Range in standard air
Alpha Particle	Heavy positively charged particle. Helium nucleus He^{++}. Velocity 0 to 2 x 10^9 cm/sec.	High 4–9 Mev**	High 40,000–250,000 ion pairs; 20,000–80,000 ion pairs per centimeter	5.5 Mev—4.06 x 10^{-3} cm in Aluminum	7 Mev—6.0 cm 5 Mev—3.48 cm 2.0 Mev—1.0 cm 0.2 Mev—0.17 cm
Beta Particle	Light negatively charged particle. Electron e^-. Velocities up to 99.7% that of light	Up to Medium High, 0–3 Mev	Medium 30–300 ion pairs per centimeter	0.15 Mev—1.0 mm; 2 Mev—3.5 mm in Aluminum	0.2 Mev—37 cm 2 Mev—840 cm
Gamma Ray	Electromagnetic radiation. Wave length from 5 x 10^{-10} to 4 x 10^{-8} cm. Uncharged	Low to Medium High, 0.03 – 2.6 Mev	Low 0+	Lower intensity expotcntially along its path	Thickness to reduce intensity of 1 Mev to one-half: Air—350 feet Lead—0.9 cm

**Mev=Million electron volts=amount of work done when one electron is accelerated by a potential difference of one million volts.

*Numbers in parentheses indicate references on page 83 of this manual.

1263395

2.02 Electrically Neutral Radiation

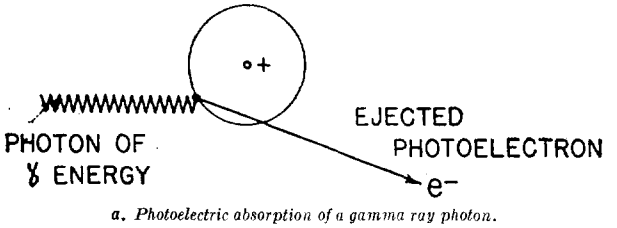
The fact that gamma (or X-rays) are uncharged means that it is not possible to detect them directly with present types of measuring equipment. Fortunately these radiations in their passage through matter produce secondary processes which allow measurement.

In order to understand the methods of measurement of gamma rays, it is necessary to consider the manner in which neutral radiation is absorbed. It can be shown that absorption, or attenuation, takes place by several processes, the most important being the following:

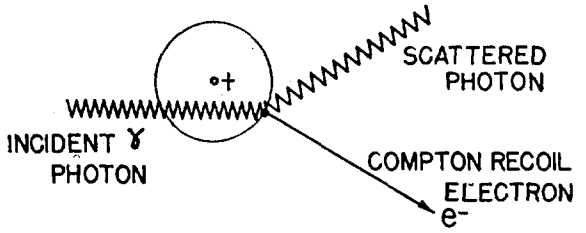
A. Photoelectric Effect

As shown in figure 2a, an atom irradiated with gamma rays absorbs the radiation by ejecting an electron. This type of absorption is dependent on the absorbing medium, but as a rough rule, is only important with gamma rays having energies below 0.1 Mev.

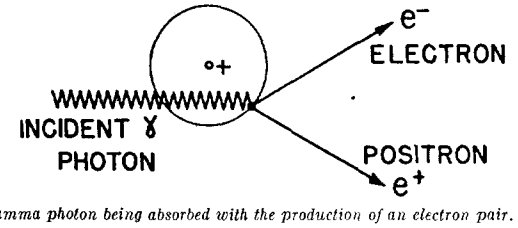
B. Compton Effect



a. Photoelectric absorption of a gamma ray photon.



b. Gamma ray photon absorbed through the production of a lower energy gamma photon and a recoil electron.



c. Gamma photon being absorbed with the production of an electron pair. This only occurs in the vicinity of the nucleus.

Figure 2. Gamma ray absorption.

Three methods of gamma ray absorption are shown by means of schematic diagrams. It will be noted that a negative electron (e^-) is produced by each method.

In some cases, photons of gamma radiation behave like billiard balls and produce the effect shown in figure 2b. Energy is absorbed from the incident photon to eject an electron. The scattered photon has, as a result, lower energy than the incident photon. This effect is important in the range of energies up to roughly 1 to 10 Mev.

C. Pair Production

With high energies above 1 Mev, pair production becomes possible, and becomes predominant in the region 5–12 Mev and above, being more important in absorbers of high atomic weight. Diagrammatically, this is shown in figure 2c where a high energy gamma photon is absorbed by producing a pair of electrons. As shown all three methods of absorption result in the production of high energy electrons which are electrically charged particles of the same general type as beta particles.

It should be reemphasized that only if uncharged radiations are instrumental in producing charged radiations through some secondary process can they be detected or measured by the various means which will be discussed.

2.03 Electrically Charged Radiation

Several possibilities present themselves for the measurement of electrically charged particles. Methods employing gas ionization prove to be the most convenient and practical. When a charged particle enters a gas it may act on a neutral gas atom or molecule with sufficient energy to remove one or more electrons. This process is called *ionization* and results in a single neutral atom or molecule being split into two (or more) electrically charged particles—the negative electron(s) and the positively charged remaining portion of the atom or molecule. The removal of a single electron produces what is called an *ion pair*. The energy required to produce ion pairs depends upon the particular gas involved. In the case of air, which is a mixture of gases, the average loss of energy by the electrically charged particle is about 32.5 electron volts for each ion pair produced. This does not mean that 32.5 electron volts go into the formation of the ion pair. Actually, only about half of this value is used specifically to strip off the electron in an ionizing collision. The remainder of the 32.5 electron volts is given up in the excitation of gas molecules in inelastic collisions which do not produce ions or in providing kinetic energy to the members of

1263396

and ion pair if ionization is produced. We will discuss later the excitation phenomenon in connection with certain crystals, but for the moment ionization is of the greatest interest.

In the process of ionization, particles having greater electrical charge will produce greater ionization. Also, the more massive particles moving with lower velocities will present longer periods of time in which forces can act and, as a result, will be more effective in producing ionization than less massive particles. As an example, the transit in air of the negatively charged beta particle will produce between 30 and 300 ion pairs per centimeter of path length with the higher ionization occurring for lower beta particle energies. The heavier, doubly charged positive alpha particle will produce anywhere from 20,000 to 80,000 ion pairs per centimeter of travel.

The ion pairs produced in a gas by the transit of an electrically charged particle will recombine to form neutral molecules. In the case of air at atmospheric pressure the life of an ion pair is believed to be in the order of five minutes. If, prior to recombination, the particles are subjected to an electric field, they will move under the influence of the field, the positive ions toward the negatively charged cathode, and the negative ions toward the positively charged anode. A gas filled chamber containing electrons which have sufficient strength to collect all of the initially formed charge is called an *ionization chamber*. The electric field strength required for charge collection in chambers generally is between 15 and 120 volts per centimeter and usually is not critical. This voltage corresponds to the field necessary to collect the ions prior to appreciable recombination and is not high enough to produce additional ion pairs as the ions travel to the collecting electrodes.

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Chapter 3

IONIZATION CHAMBER

3.01 Introduction

With appropriate forms of chambers all ionizing radiations can be detected (4). In the case of heavily ionizing radiations such as alpha particles (and in some cases electrons), separate ionizing events can be counted in a manner similar to that which will be described for Geiger-Mueller and proportional counters. Design characteristics of instruments are thoroughly entwined with operational usage and the type of radiation involved. In general, the chambers are built around three basic forms:

A. Two parallel electrode plates, one highly insulated and directly connected to the measuring part of the instrument.

B. Cylindrical electrode with a coaxial collecting rod.

C. Rectangular box with an internal collecting network (sometimes called a *Christmas tree*). In practice, form C is little more than an adaptation of the cylindrical condenser in B.

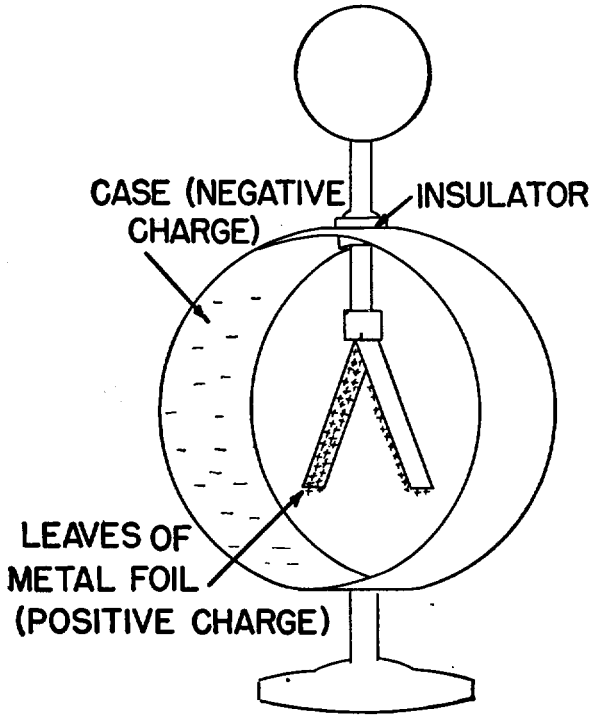

Figure 3. Laboratory type electroscope.

Separation of leaves is caused by the repulsive force between two like charges.

The anode and cathode previously mentioned, may take the form of electrodes in a simple electroscope in which the chamber (container) forms one electrode and the central wire and thin gold foil form the other electrode as shown in figure 3.

The electrostatic field produced by the positive charge on the central electrode and the negative charge on the case exerts a force on the charge on the gold leaves which causes the leaves to separate. Ions formed inside the chamber by radiation will neutralize the charge on the gold foil leaves, and the leaves will move together. Thus, within certain limits, it is possible to read radiation dose as a function of position of the sensitive element of an electroscope (3). An *electroscope* has no external voltage source, however, if the instrument used for the measurement of the electric charge collected in an ionization chamber utilizes a continuous external voltage for its operation it is called an *electrometer*.

3.02 Pocket Dosimeter

A useful military instrument is the *quartz fibre pocket dosimeter* which is a modified version of the *Lauritsen Electroscope* (1). A dosimeter is pictured in figure 4. This instrument, about the size of a fountain pen, utilizes a metallic coated quartz fibre some five microns (0.0002 inch) in diameter as the sensitive moving element in place of the thin gold foil in our previous example. The instrument incorporates a small compound microscope for viewing the fibre against a calibrated scale. Some type of light source must be available in order to see the scale and fibre. These dosimeters, having a full scale sensitivity 0.2 roentgen (r),* are in common use for measuring integrated gamma ray exposures. Work is under way to produce pocket dosimeters having full scale readings, perhaps as high as 200 roentgens. Pocket dosimeter reading and charging is shown in figures 5 and 6.

*See page 52 for an exact definition of a *roentgen*. (This is a unit of measurement of gamma or X-ray dosage rate or absorption.)

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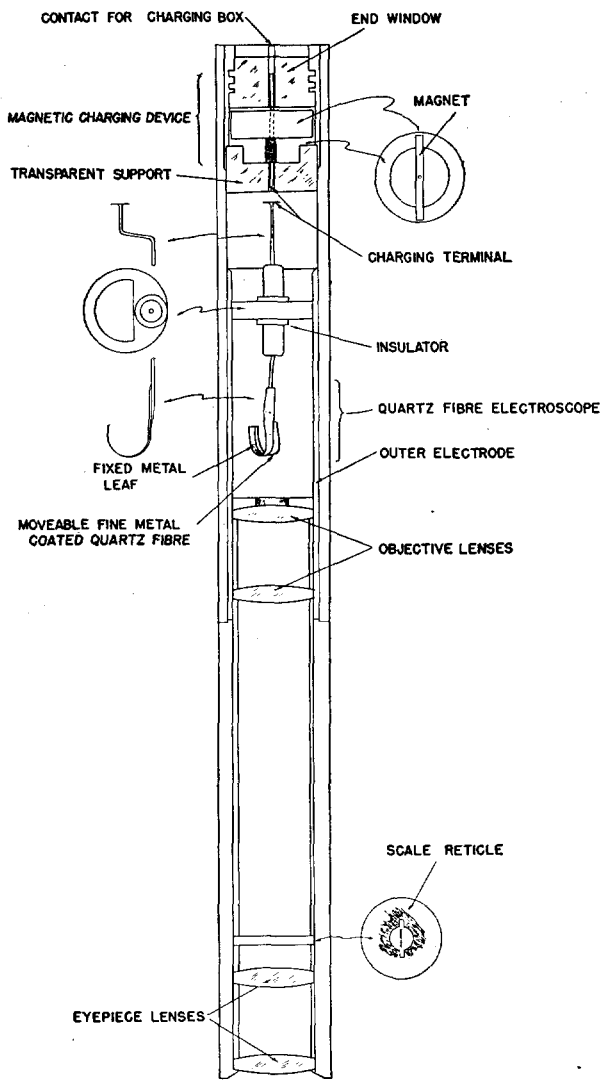

Figure 4. Pocket dosimeter.

Shown is the dosimeter with the magnetic charging device recently developed by Dr. F. R. Shonka of the Argonne National Laboratory. A magnet in the charger repels the dosimeter magnet and moves it into position so that the electroscope can be charged. Many dosimeters incorporate diaphragm charging terminals such as that shown with the pocket chamber in figure 8.

3.03 Drift Meter

A medium sized portable gamma measuring, alpha and beta indicating, survey instrument has been built with a quartz fibre system similar to that used in the pocket dosimeter. In some areas this instrument goes under the name *Landsverk Electroscope*. The unit has an enlarged chamber and is designed for portable but not pocket use. Since it is not a pocket device the charger is built

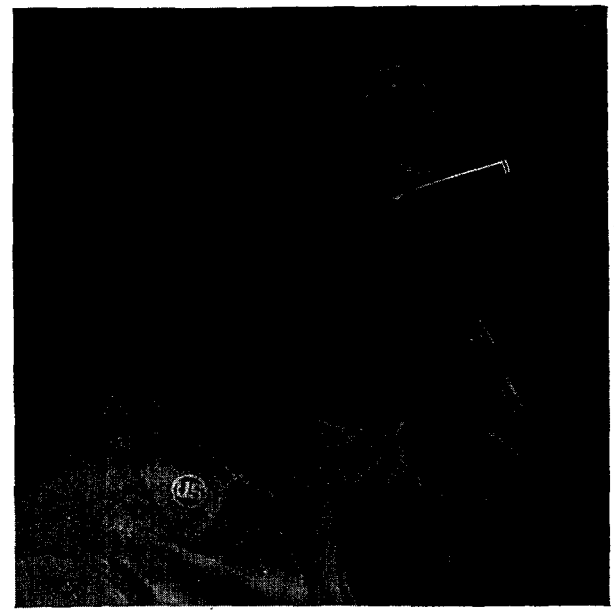

Figure 5. Reading the pocket dosimeter.

A light source must be available to see the scale and fibre. Here a reading is made using sky light for illumination.

in as a part of the instrument. Dosage rate is obtained by timing the rate of electroscope fibre movement. Timing is accomplished by the repetitive flashes of a neon lamp which appears to the viewer just above the microscope scale. Since the instrument keeps its calibration over extended periods of time, it is used as a secondary standard.

Figure 6. Charging a pocket dosimeter.

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Chapter 4

GAS AMPLIFICATION

Ionization chamber voltages are relatively weak. However, if higher voltages are applied to the chamber electrodes, a gas amplification can be obtained (5). When the electron from an ion pair is given greater energy than the ionization energy of the atom or molecule of a gas, it may produce additional ionization as shown diagramatically in figure 18. Gas amplification also can be obtained by reducing the energy required to ionize the chamber gas through the choice of a suitable gas or by decreasing the chamber pressure so as to increase the mean free path and the energy of the ionizing particle.

If we consider the counting chamber and circuitry as shown in figure 19 with the chamber exposed to a constant energy source of radiation, each particle entering the chamber will produce a definite number of ion pairs, and these ions will be collected at the electrodes, thereby producing a pulse of current in the external circuit.

If the size of the pulse is plotted as a function of the voltage applied to the electrodes, a curve such as that shown in figure 20 is formed.

Below a certain minimum voltage across the chamber we do not collect all the ions which are formed, because in this region of low voltage, *0–a*, ions have an opportunity for recombination prior to collection. At slightly increased voltages, *a–b*, normal ionization chamber working conditions are reached. Above voltage *a* the pulse size becomes relatively independent of the voltage, since there is a complete collection of all ions formed by the

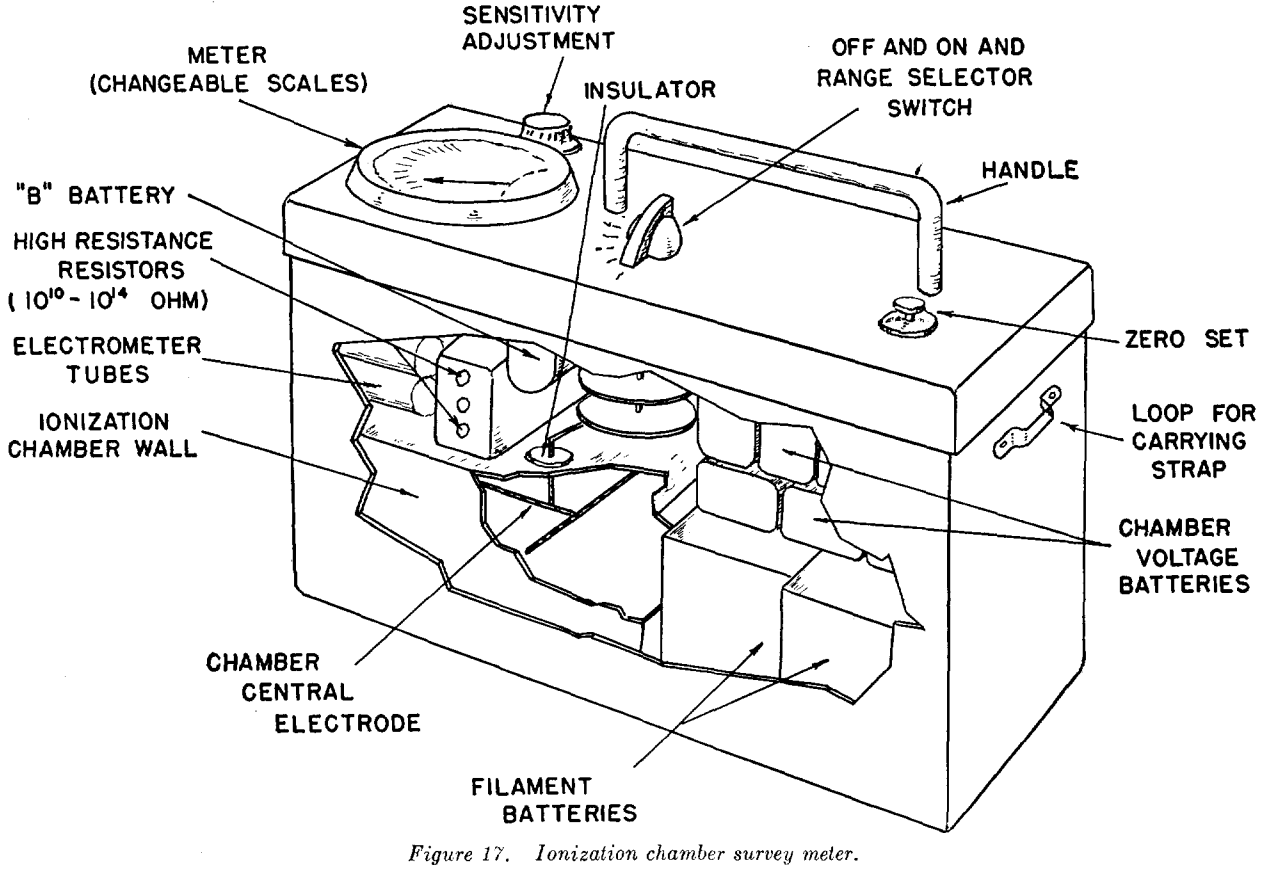

Figure 17. Ionization chamber survey meter.

Gamma-measuring instruments of this type are probably the most important military survey instruments.

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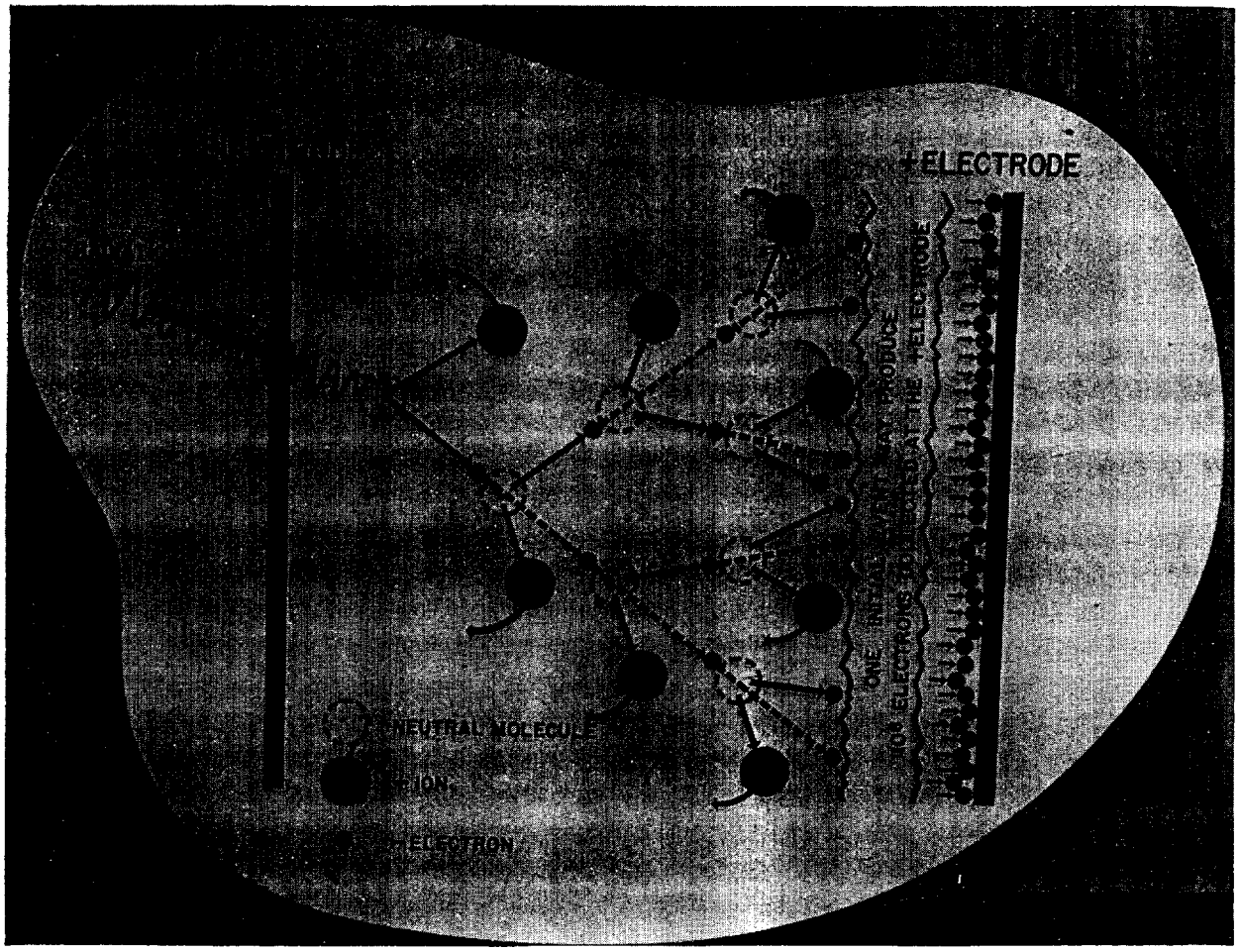

Figure 18. Gas amplification.

Diagramatic representation of the avalanche type of gas amplification found throughout the Geiger-Mueller tube and near the collecting electrode of a proportional counter. One initial ionizing event may produce 10^3 electrons collected in a proportional counter and 10^8 electrons collected in a Geiger-tube.

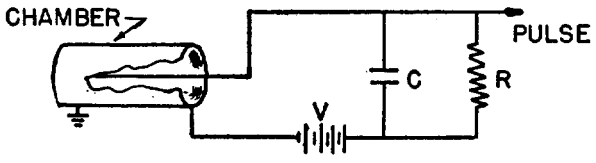

Figure 19. Counting chamber and circuit.

passage of an ionizing particle. In the region *0–a–b*, only ions produced by the primary radiation contribute to the pulse. In the region *a–b* the pulse P in volts will be given by the relationship:

$$P = \frac{Nc}{q}$$

where:

N = Number of ions collected

c = Charge on the electron (coulombs)

q = Capacity of the system (farads)

If we assume the capacity of the system to be 10^{-11} farads and examine the voltage produced by 1 centimeter of travel of a 1 Mev alpha particle, then:

$$P = \frac{(4\times10^4)(1.6\times10^{-19})}{10^{-11}} = 6.4\times10^{-4} \text{ volts}$$

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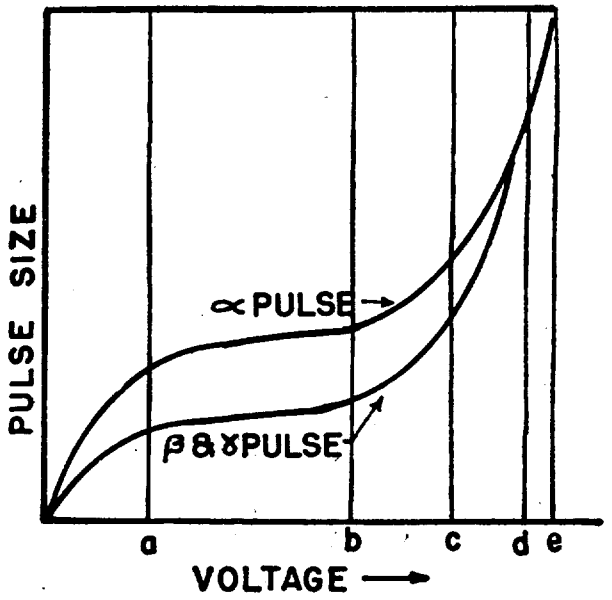

Figure 20. Pulse size as a function of voltage from a chamber exposed to a constant energy source of radiation.

a–b	Ionization chamber region
b–c	Proportional region
c–d	Limited proportional region
d–e	Geiger region
above *e*	Continuous discharge region

The same length of travel with a 1 Mev beta particle:

$$P=\frac{(30)(1.6\times10^{-19})}{10^{-11}}=4.8\times10^{-7}\text{ volts}$$

One would expect a slightly larger voltage, say 4 x 10^{-7} volts to be produced as the result of the secondary electron produced in the absorption of a 1 Mev gamma ray. Assuming photoelectric absorption of the gamma ray, some energy is required for ionization, some energy will perhaps go into kinetic energy of the products of ionization, and there may be some excitation of other electrons in the ionized atom. At any rate, it would be expected that the photoelectron would be produced with very slightly less energy than the 1 Mev beta particle and because of its lower velocity (see page 4) will produce a slightly greater number of ion pairs per centimeter of travel in the chamber. If the chamber is such as will expend all the energy of the beta particle or photoelectron, the total number of ion pairs produced by the beta particle will be slightly in excess of those produced by the gamma ray photoelectron.

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Chapter 5

PROPORTIONAL COUNTER

5.01 The Proportional Region

At some higher voltage *b* in figure 20 the above relationship would cease to exist, and pulses would be found larger than predicted. The region *b–c* is the so-called *proportional region*, because the output pulse is directly proportional to the amount of primary ionization. The chamber operation in the proportional region can be explained as follows: In the region of a few electron mean free paths away from the central (anode) wire, a sufficiently high field strength imparts to electrons, attracted from the remaining chamber volume, enough energy to cause secondary ionization. The output pulse is therefore increased by the collection of the additional electrons and is proportional to the magnitude of the initial ionizing radiation.

If there are I ion pairs formed by collections as an electron travels toward the central electrode, then the size of the voltage pulse is given by—

$$P=\frac{(I)(1.6\times10^{-19})}{q}$$

Here, "I" is defined as the gas amplification and is the ratio of the number of electrons collected at the anode N to the number of ion pairs originally formed in the gas N_o:

$$I=\frac{N}{N_o}$$

It should be noted that the gas amplification factor varies from about 10 in certain photoelectric cells to 10^3 in proportional counters and to 10^8 in some Geiger-Mueller counter tubes as shown in the diagram in figure 18.

In the case of the proportional counter it is necessary that the secondary ionization (or amplification) occur less than ten electron mean free paths from the central wire. Otherwise strict proportionality ceases, and the *limited proportional region c–d* is entered where the gas amplification factor has values from 10^4 to 10^7.

Since the total ionization produced by an ionizing particle is dependent on the type of particle, it follows that in the proportional counter region we are able, within limits, to differentiate between the pulses produced by alpha particles and the pulses produced by either beta or gamma radiations. This means that the proportional counter will have a limited military usage for alpha measurements. If the field strength is such as to form a beta-gamma to alpha ratio of 10^5 or greater, such as roughly approximates the case immediately following an atomic bomb explosion, the proportional counter is not capable of differentiating between the combined effects of a multitude of smaller beta and gamma pulses and the large alpha pulses. The proportional counter has a definite use in decontamination work after the decay of the short half-life gamma and beta emitters. A portable proportional counter survey meter is sketched in figure 21.

Certain factors must be considered in order to establish good working characteristics for proportional counters. The gas used for tube filling may be chosen so as to accomplish the desired action. Pure argon, helium, neon and methane, and certain combinations of these gases have been found to give satisfactory results. Other counter probes are left open to the air. Strong electric fields may be produced with moderate voltage by using two coaxial cylinders as the electrodes, and since the field strength varies logarithmically for a cylindrical configuration, the smaller the diameter of the anode, the higher will be the field strength in the vicinity of one electron mean free path of the wire. For this reason, extremely fine central electrode wires are employed. It is readily seen that the mechanical strength of a thin window tube with a 0.0005 inch diameter central wire is not such as to lend itself readily to field use.

5.02 Proportional Counter Probe

As previously stated, a counter for use in the proportional counter region is restricted in the multiplication of electrons to somewhere in the order of ten generations. This can be obtained in the large electric field near the central wire in the cylindrical arrangement described above. It follows that a parallel plate structure is excluded

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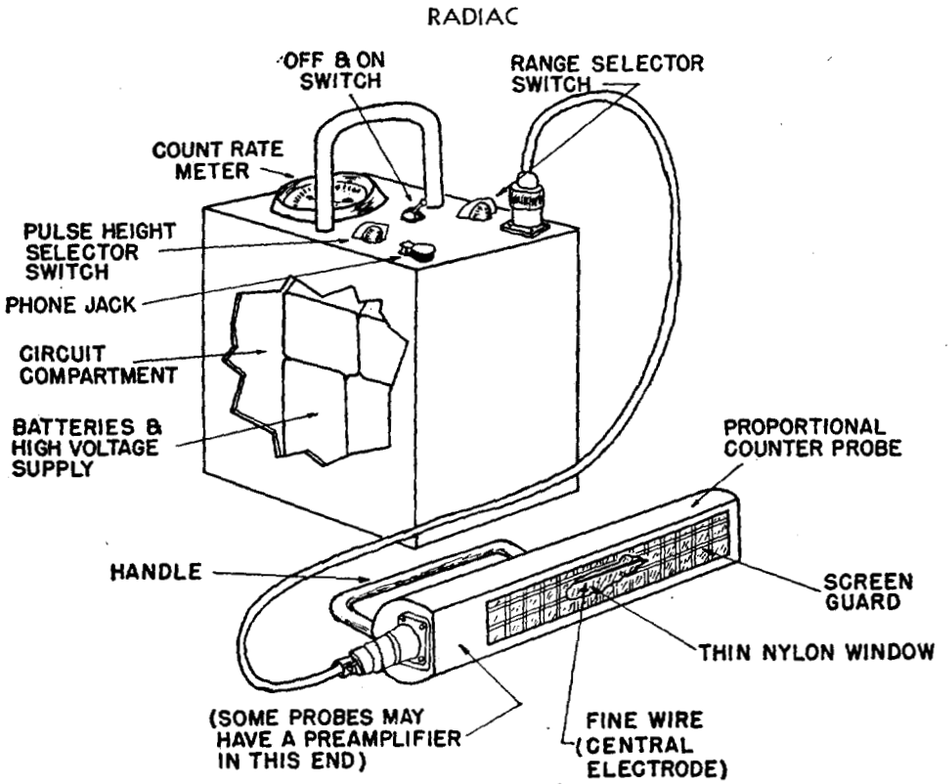

Figure 21. Portable proportional counter survey meter.

This type of instrument will be used for alpha particle detection.

for use in a proportional counter. It is possible to build proportional counter probes with large windows using a number of parallel wires. A satisfactory geometrical configuration has been found where the depth of the chamber behind the window is "x", the wires are placed at a depth "x/2" and a distance "x" apart. In some probes, "x" has been chosen equal to one centimeter. Such a multiple wire probe is shown in figure 22. A single wire probe is shown in figure 21. In this latter example the probe case is not completely cylindrical since the window opening is cut longitudinally along the side wall.

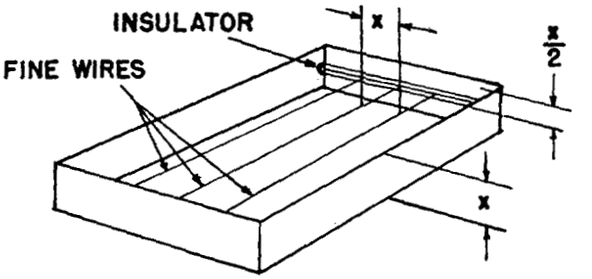

Figure 22. Parallel wire proportional probe.

A satisfactory geometrical arrangement has been found with x=1 inch.

Parallel wire counters having large sensitive openings (100—150 cm^2) are used for the survey of large areas. Proportional counters with probes are used for checking alpha contamination on hands, feet, clothing, filter paper samples, and various surfaces. This is primarily a tool used in conjunction with a field laboratory and with decontamination activities.

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Chapter 6

GEIGER-MUELLER COUNTER

6.01 Avalanche Ionization

If in our previous example (fig. 20) the voltage is raised still further above point *c* the gas amplification factor will continue to increase, but in the region *c–d*, the amplified pulses are no longer proportional to the initial ionization. This means that secondary ionization is started outside the distance of a few electron mean free paths from the central wire. There is still some difference in final pulse sizes so that this region *c–d* is known as the *region of limited proportionality*. Tubes operated in this region have little application outside research laboratories.

If the voltage is increased still further, a new phenomenon occurs in which secondary ion multiplication spreads throughout the entire chamber volume. This cumulative effect is known as *Townsend* or *avalanche ionization* and is shown diagrammatically in figure 18. When a chamber is used in this region *d–e*, it is called a *Geiger-Mueller counter*, and the pulse size is independent of the event which initiated it. Still higher voltages produce above point *e* a *region of continuous arc discharge*. While in effect this is not a continuous discharge but a series of pulses so closely spaced to give that appearance.

It should be noted that for any particular counter tube, if the pressure is held constant and the voltage is varied the instrument can be made to operate as either an ionization chamber, proportional counter, or Geiger counter. By holding the voltage constant a similar situation can be created by varying the mean free path through variations in gas pressure.

An examination of pulses from a Geiger-Mueller tube reveals that pulses are of the same size only when spaced a good time apart. One would expect all pulses to be of the same size, but an examination of the action of the positive ion reveals that this is not always the case. In previous discussions of the operation of ionization chambers and proportional counters we have neglected the effect of the positive ions and considered only the action of the electrons. Because

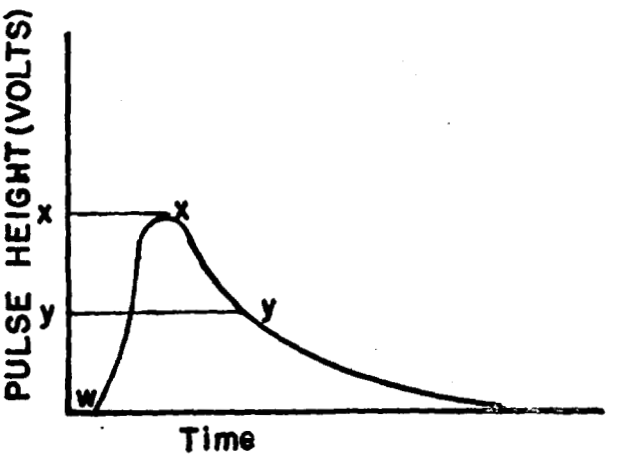

Figure 23. Geiger-Mueller tube pulse.

After one pulse has started at *w*, no second event can take place until the pulse reaches *y*. The time *w–y* is the tube *dead time*.

of their mass, the positive ions move slowly under the influence of the electric field reaching the outer collecting electrode in perhaps 10^{-3} seconds. The electrons formed during the Townsend avalanche, being many orders of magnitude (10^4) lighter, are all collected in less than 10^{-6} seconds, which is a long time before the positive ions reach the cathode. The result is a cloud of positive ions forming at a distance of several mean free paths from the anode and moving toward the cathode. This produces a positive space charge which for a time completely shields the anode and prevents counter action. As the positive charge moves closer to the cathode, a limited counter action is allowed to occur. In this case the initial pulse will be of greater magnitude than that of the one which follows. An examination of the pulse delivered by a Geiger-Mueller tube may be made with the help of figure 23.

The pulse develops rapidly from *w* to *x*, due to the rapid collection of electrons. The pulse decays more slowly from *x* to *z*, due to the longer transit time of the positive ions and the time constant of the external circuit. After one pulse has started at time *w*, no second event can take

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place until the pulse has reached y, due to the shielding action of the positive space charge. The time w–y, in which no second event can take place, is called the tube *dead time*. This time is very important, because it determines the maximum counting rate of the tube and its allied circuit. In portable survey instruments the dead time is approximately 0.0005 second which allows a maximum counting rate of 2,000 pulses per second. It becomes apparent that since the maximum tube response is Vx; then pulses occurring after time y will have a minimum amplitude of Vx–Vy. This amplitude will increase with time to Vx at time z. Therefore, during the time of pulse decay starting with the end of the dead period, there will be a period y to z with pulses less than normal height.

If we assume a Geiger-Mueller tube to be exposed to a constant intensity source having a wide spectrum of energies of gamma photons or beta particles; then a typical Geiger-Mueller tube characteristic curve of pulses per second as a function of voltage may be plotted in figure 24.

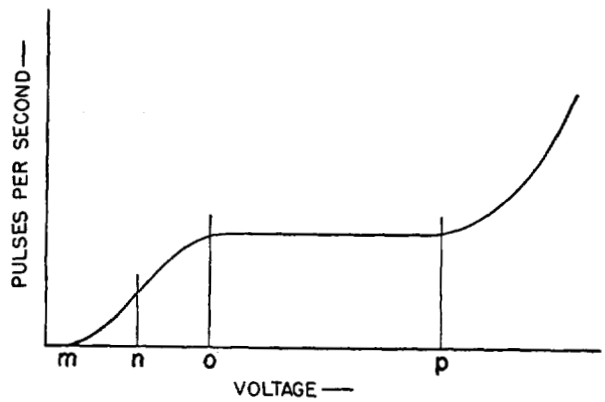

Figure 24. Geiger-Mueller tube characteristic curve.

- m Curve threshold
- m–n Region of proportional counting
- o Threshold of Geiger region
- o–p Plateau
- p Start of continuous discharge region

There will be no response to the small pulses in the ionization chamber region where there is no gas amplification. A threshold m appears early in the proportional region. This region extends from m to n. As the voltage is increased, the gas amplification becomes increasingly more important with more of the less energetic particles being counted. At o the *threshold* of the *Geiger region* o–p is reached, and within the resolving time of the tube practically every particle entering the tube which is capable of producing at least one ion pair in the tube gas is counted. Beta particles which penetrate the tube walls will be counted with almost 100% efficiency; on the other hand, gamma rays must produce ionization in the tube in order to be counted. The gamma counting efficiency usually is considered less than one per cent. The region of continuous discharge begins at p.

The Geiger portion of the characteristic curve o–p is known as the *plateau*. It is desirable, particularly in portable battery operated survey meters, to have a long, flat plateau; since the counting rate does not depend on applied voltage and, within limits, will not be affected by battery aging. Tubes having plateau lengths from 100 to 300 volts and slopes showing an increase in counts of only one to two per cent for a change of 100 volts are in general usage. In many portable survey instruments these tubes operate with the threshold of the Geiger region in the neighborhood of 900 volts. In the laboratory equipment various tubes operate up to 2500 volts. Most of the portable radiac instruments are necessarily restricted to batteries, and the higher the voltage, the larger and heavier the battery requirements. Efforts are under way to develop satisfactory high voltage supplies* which operate from low voltage batteries. This is only a temporary expedient until satisfactory low voltage Geiger-Mueller tubes are developed. Constant voltage power supplies will reduce the requirement for a long plateau although tube aging with use many times causes voltage shifts in the characteristic curve which makes the plateau desirable.

6.02 Quenching the Discharge

The approach of the positive ion cloud to the cathode cylinder will result in pulling electrons from the cathode to produce neutral atoms or molecules. The electron usually enters combination with the positive ion in an excited state. The process of transit to the ground state produces a characteristic series of spectral radiation, and some of these radiations will be in the ultra-

*There are essentially nine different types of power supply which can be used to provide the high voltage required for Geiger counter operation: Battery, condenser, condenser-commutator, vibrator, condenser-vibrator, radio frequency, fly-back, transformer (AC supply), and multiplier (AC supply).

1263414

violet region. This ultra-violet radiation usually has sufficient energy to produce photoelectron emission from the cathode. These photoelectrons, in turn, will have sufficient energy to start a second avalanche, and the whole process will be repeated. It is therefore necessary to construct counters in which the cycle is halted for each individual pulse. This process is called *quenching* and can be accomplished by using external electronic methods or by using special vapors inside of the counter tube.

All external quenching methods work on the principle of lowering the collecting electrode voltage below that at which the counter can form an avalanche until such time as the danger of an additional avalanche is passed (3) (5). The recovery time for resistance quenched circuits is in the order of 10^{-2} seconds. The Neher-Harper circuit, a good example of vacuum tube quenching, is shown in figure 25. This circuit has a recovery time in the order of 10^{-4} seconds.

When current flows as the result of a discharge of the detector, the resistor R_1 raises the vacuum

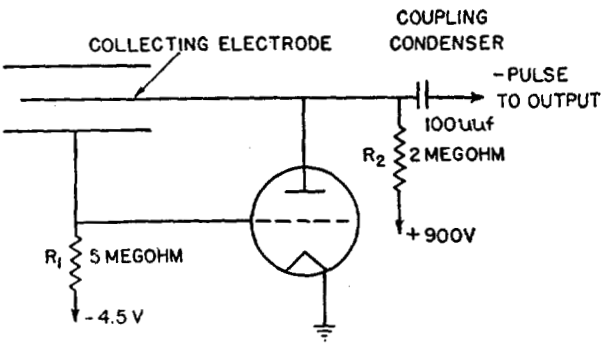

Figure 25. Neher-Harper vacuum tube quench circuit.

tube grid potential. As the grid becomes positive from its normal −4.5 volt bias, the tube conducts, thereby dropping the potential on the collecting electrode. Other quench circuits in use are the Neher-Pickering, Getting multivibrator, and a number of combinations and variations.

Internally quenched Geiger-Mueller tubes utilize small amounts of polyatomic vapor such as ethyl ether, amyl acetate, ethyl alcohol, etc., mixed with the regular tube gas in order to cause the detector

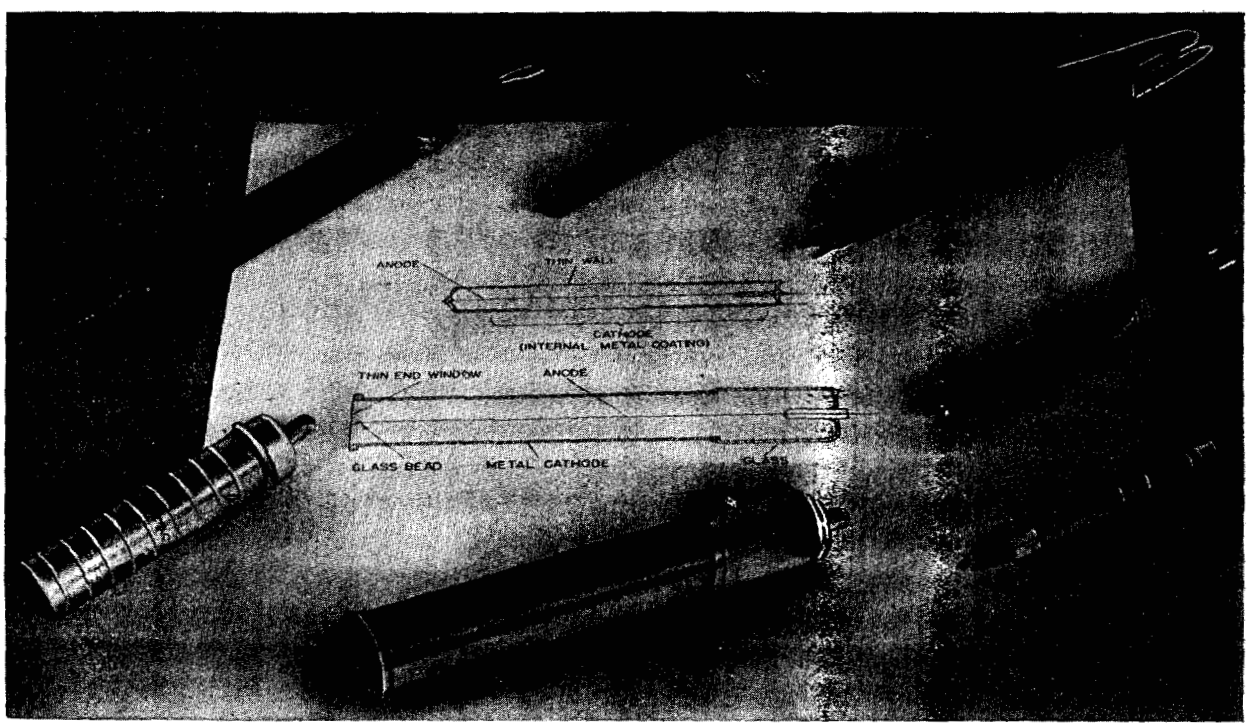

Figure 26. Tubes for portable Geiger-Mueller counters.

The diagram indicates the difference between thin wall and thin end window tubes. The Victoreen all metal thyrode 1B85 is shown in the lower left. The thin-end window tube is the BS–1 used for beta-gamma indication in the AN/PDR–8 series, –15 and –27. The BS–2 for high range gamma detection in the same instruments is shown in the lower right. An assortment of thin-walled tubes from other portable counters is shown.

1263415

to quench itself after each discharge. These Geiger-Mueller tubes are known as *self-quenching*. The primary function of the vapor molecules is the absorption of ultra-violet photons, thereby forestalling any repetitive discharge. The majority of the quenching gases are complex organic molecules such as alcohol or xylene which preclude their use under subzero weather conditions. They also may show changes in sensitivity with changes in temperature at room conditions. One of the most severe problems presented by the quench vapor is in limiting the life of the tube. Some of the quenching vapor is dissociated at each discharge, and eventually the vapor is completely used up and the tube goes into a repetitive discharge condition. The better tubes in survey equipment will have a life of 3×10^9 counts. For continuous operation in a field which will just allow utilizing a 10^{-4} second resolving time, the tube life will be only 100 hours.

Considerable work is under way toward the development of Geiger-Mueller tube fillings which will overcome the difficulties that have been enumerated above. Halogen gas mixtures are among the most promising. Tubes have been constructed with the Geiger threshold in the neighborhood of 700 volts, having a virtually flat plateau of several hundred volts. These tubes appear to have good temperature characteristics and a life well in excess of that for tubes generally employed in survey equipment.

The majority of Geiger-Mueller counter tubes presently employed in survey meters are ⅜ inch in diameter and 5¾ inches long. The cathodes vary from one to three inches in length. In common use are thin side walls of 30 mg/cm² thickness. Others have thin end windows in some cases 3 mg/cm² thick. Such tubes are shown in figure 26. Laboratory counter tubes range up to 3½ inches in diameter with the length from two to ten times the diameter. Several laboratory Geiger-Mueller tubes are shown in figure 27. The anode, thoroughly insulated from the cathode, is a fine wire from 0.0001 to 0.0010 inch in diameter running down the cathode cylinder axis. To obtain a satisfactory characteristic curve, the central wire must be manufactured carefully, free of die marks and sharp protuberances. The tube must be cleaned carefully to remove all dust, grease, water vapor, and oxygen; and special care must be exercised in the selection of pure filling gases. In addition, the filling gas pressure must be chosen carefully. Most tubes used in radiac equipment of the portable survey type incorporate thin windows to permit some beta counting. Normally, this is a cylindrical section of tube wall approximately 2 inches long at mid-tube length as shown in figure 26 and having a thickness of 30 mg/cm². Provided the probe housing tube does not add additional shielding, the tube then will be sensitive to beta particles having energies above 0.16 Mev. As previously stated, counter tubes may be employed with thin end windows such as that illustrated in figure 26. Tubes of this type of construction are in more common use in laboratory equipment than in equipment used for field survey work. Mica windows down to 0.5 mg/cm² are available, although in normal laboratory work the thin windows run between 1.5 and 4 mg/cm² in thickness.

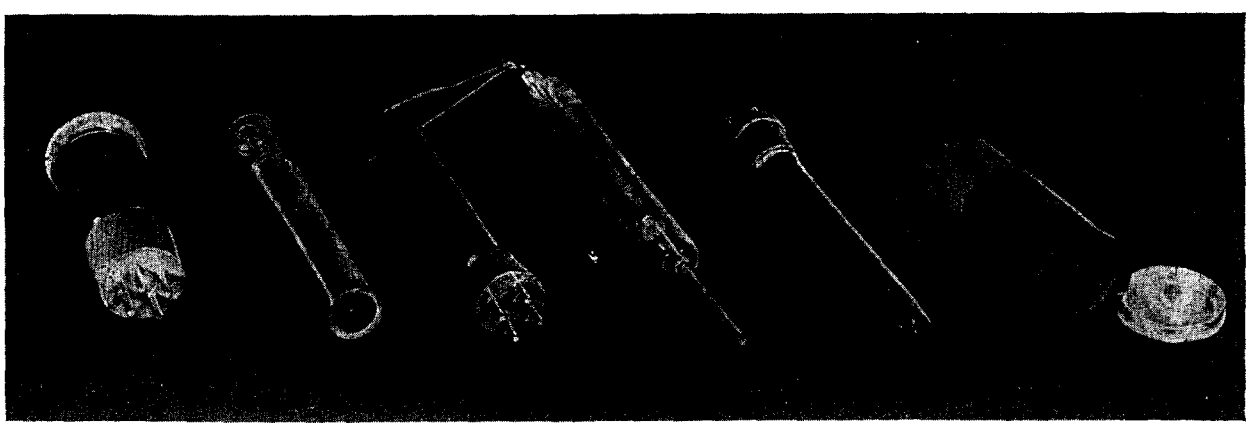

Figure 27. Laboratory Geiger tubes.

A number of tubes have been developed to cover the wide range of requirements of laboratory counting.

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A great majority of Geiger-Mueller tubes are photosensitive. This undesirable feature has been overcome by coating the glass envelope with an opaque surface. Occasionally, pin holes in the thin opaque coating will cause spurious counts when the tube is exposed to bright sunlight. In addition, the opaque coating has been known to peel off a once satisfactorily operating tube and introduce serious counting errors.

6.03 Portable Geiger-Mueller Detector

Geiger-Mueller counters, utilizing self-quenching tubes, are especially useful as light weight highly sensitive detecting instruments for field

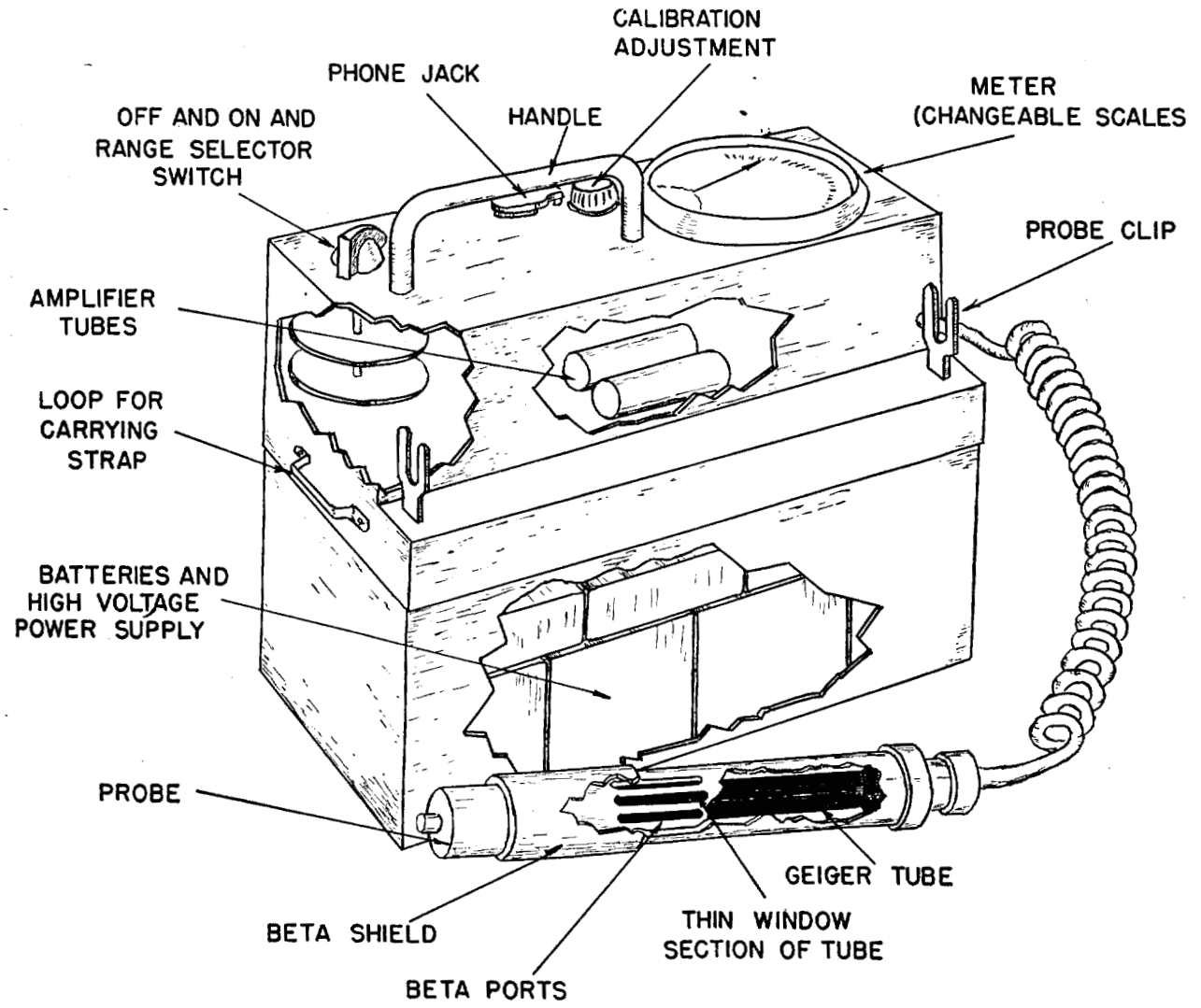

Figure 28. Diagramatic sketch of a portable Geiger-Mueller survey meter.

The probe, foreground, has a descriminating slide which may be used for beta indications. Indication is by the meter and by headphones (not shown).

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Chapter 7
SCALING CIRCUITS

Field laboratories will be used to evaluate samples of terrain, food, water, etc., to determine the nature and extent of radiological hazards. This work requires that accurate counts be made. The best mechanical counters can be driven at rates of perphaps no more than 300 times per second; therefore, other means are required to record the maximum Geiger-Mueller count in the neighborhood of 5,000 pulses per second. Electronically, it is possible to record pulses at rates far in excess of the best counter tube output. Some of these electronic arrangements are known as *scaling circuits*.

Scaling circuits are based upon a basic two-tube circuit which divides the number of pulses by two, and by constructing a series of such circuits, the pulses can be reduced by factors of 2, 4, 8, 16, 32, 64, 128, etc. The most common scaling circuits in use utilize scales of 64. Recording is accomplished by neon indicator lamps at each stage multiple of the circuit. The sum of all indicator lamps will give the number of pulses counted. Since 64 or more counts per second are not uncommon, the circuit is set to drive a mechanical register which records the total number of 64 counts which have taken place. A greatly simplified scale of two scaling circuits is shown in figure 30. Essentially, the two plates are joined by a relatively large capacitor C_1 of the order of 0.1ufd. The two cathodes are tied together through the identical resistors R_1 and R_2 and held at some small negative bias. Because of the cross coupling by capacitor C_1, the circuit will be in equilibrium when either tube is cut off and the other at maximum plate current. An impulse having fired T_1 causes the grid of T_2 to go negative with respect to the cathode and not fire. However, the arrival of a second impulse gives a momentary positive bias to the grid of T_2 and accordingly it fires.

Certain difficulties are inherent in translating powers of 2 into multiples of 10; therefore, electronic circuitry is being devised to give readings of decades (units of 10), and all military field laboratory equipment will probably be so constructed.

Scaling circuits can be used in conjunction with any type of pulse detection. Many instruments are constructed with high voltage power supplies

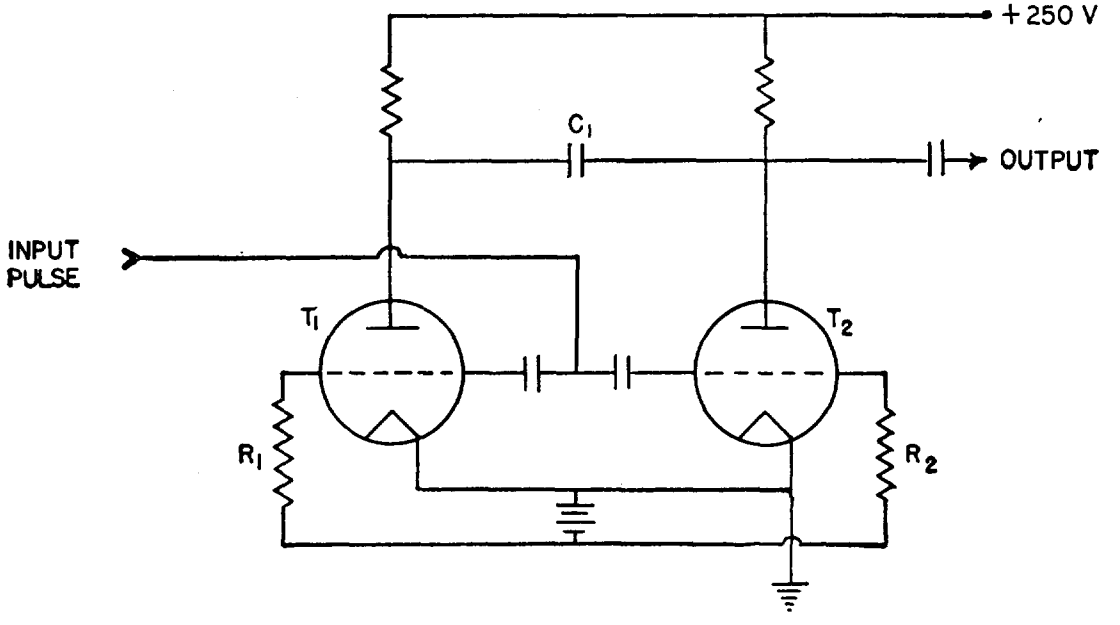

Figure 30. Simplified scale of two scaling circuit.

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Chapter 9

CRYSTAL AND CHEMICAL DETECTION

9.01 Excitation

As previously shown, an electrically charged particle in its passage through a gas may come close enough to an atom to exert sufficient force to remove an electron and ionize the atom. In many cases the charged particle will not exert enough energy to cause ionization, but will cause one or more of the atom's electrons to be raised to higher energy levels. The excited atom in returning to its ground state will radiate a characteristic series of spectral lines. Some liquids or solids subjected to ionizing radiation may give off a characteristic fluorescence which can be measured. In addition, the free electrons produced in a solid or liquid by ionization may cause changes in the electrical conduction of the substance in which they are produced. This latter process is sometimes referred to as *photo conduction*.

Some crystals do not return immediately to a ground state after being exposed to radiation. This may manifest itself in a crystal color change. In some cases shining light on the crystal will release energy which has been trapped in the crystal excited stage. Some crystals will encounter an effective change in electrical resistance when subjected to ionizing radiation. In some cases chemical reactions which produce color changes are initiated by the disassociation of compounds, formation of free radicals or electron attachments under the influence of radiation. With the exception of photographic film badges, which will be discussed later, these various phenomena are of interest only in that some day they may be incorporated into a military dosage measuring device. Much developmental effort is being placed on a dosage indicating tag which will change colors at various levels of exposure so as to be used for rapid determination of the degree of field exposure.

9.02 Chemical Dosimeters

It appears possible to detect nuclear radiations by methods depending upon chemical change induced by radiations. Detection of radiation by chemical reactions possesses a possible advantage over detection by other methods of instrumentation, in that a single chemical method may be used to detect radiation over a wide range of intensity from a fraction of a roentgen to over 1,000 roentgens. The problem involved in such a method of detection is that of finding and controlling a chemical chain reaction capable of multiplying the radiation effect on a single molecule. The special requirements are that the nuclear radiation initiate a minimum chain length approximately 10^5 for visual perception and that it not be initiated significantly by thermal radiation at ordinary temperatures. Five possible ways in which multiplication may be achieved are:

A. Development reaction such as photographic development.

B. Explosive reactions such as benzoyl peroxide triggered by nuclear radiation.

C. Initiation of a free radical chain.

D. Psychological, such as a color reaction.

E. Thermoluminescence.

A few examples of many proposed systems for accomplishing the above multiplication are indicated below.

Phosphors. The development of a dosage indicating device in which a phosphor screen is combined with a photo-sensitive layer. The phosphor absorbs the high energy photons to which the photo-chemical layer is nearly transparent with the phosphor emitting an extremely large number of photons of ultra-violet light for each high energy photon absorbed. The photo-chemical layer absorbs the ultra-violet emission and in turn may be direct reading in shades of grey or in colors after a development process. This is an effective way to transform high energy radiation into a detectable form.

Colored Dyes. The formation of colored dyes on exposure to radiation of luecocyanides with pararosaniline.

Halogenated Compounds. The radiation decomposition of halogenated compounds can be used to produce color reactions.

Pyridine Ring. The splitting and coupling of the pyridine ring under the influence of ionizing radiation may form colored compounds.

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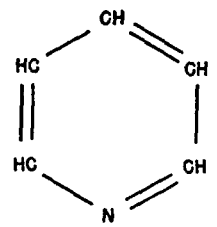

Decomposition of Carbon Tetrachloride. Carbon tetrachloride (CCl_4) in the presence of water and oxygen decomposes under radiation into chlorine (Cl_2), carbonyl chloride ($COCl_2$), and hydrochloric acid (HCl). The chlorine can be detected by the starch iodide reaction or by more sensitive and stable indicators such as thio-Michler's ketone. Other chlorinated compounds such as DDT, chloro- and hexachloroethane react in a manner similar to carbon tetrachloride.

Reduction of Mercuric to Mercurous Salts. Mercuric chloride ($HgCl_2$) or iodide (HgI_2) is reduced to mercurous (HgCl or HgI) and probably to metallic mercury by radiation. An early equilibrium is reached between the reduction products and the original salts, however, the reaction can be made to go forward by having present an acceptor of oxygen. Such an acceptor is tetramethyl diamino diphenylmethane which is oxidized to a deep blue diphenylmethane dye. A mixture of mercuric (Hg^{++}) chloride and thio-compound therefore undergoes a change from colorless to blue upon irradiation. There is a possibility that the mercurous salt (Hg^{+}) or the fine mercury formed in this reaction can be utilized to catalyze some chemical reaction which would result in greater sensitivity.

Reduction of Cupric to Cuprous Salts. Cupric chloride ($CuCl_2$) or bromide ($CuBr_2$) is reduced to the corresponding cuprous salts (Cu_2Cl_2 or Cu_2Br_2) on irradiation. It has been found that thio-Michler's ketone can be used as a sensitive indicator for this reaction since it forms deeply colored complexes with cuprous (Cu^{+}) but not with cupric (Cu^{++}) salts.

Reduction of Molybdic Acid. Molybdic acid (H_2MoO_4) is reduced slowly to a blue compound, molybdic blue ($Mo_2O_5.nMoO_3$) on irradiation. Much greater sensitivity is obtained if an organic acid such as lactic acid is present.

Reduction of Nitrates. Nitrates (NO_3^-) are reduced to nitrites (NO_2^-) by radiation. The nitrite can be detected by the formation of azo dies.

9.03 Scintillation Counters

Crystals such as Napthalene ($C_{10}H_8$), anthracene ($C_6H_4:(CH)_2:C_6H_4$), calcium tungstate $CaWO_4$), silver chloride (AgCl), thallium-activated sodium iodide (NaI), thallium-activated potassium iodide (KI), and others have been found to have a relatively high fluorescent yield. These crystals, in conjunction with light sensitive devices such as high-gain photomultiplier tubes are in use as research tools, but as yet no successful survey instruments have been delivered; however, development of such equipment is in advanced stages. It is felt that the *scintillation* type counter can be utilized to overcome many of the serious problems of high resistance, insulation, and thin windows associated with alpha counting by ionization chambers and proportional counters. In addition, it is felt that scintillation counters may provide a wide range instrument to replace the use of Geiger-Mueller counters for low intensity gamma detection and ionization chambers for high dose rate gamma survey.

Some problems are encountered with the scintillation counter. There is a spectral sensitivity problem such as that discussed in conjunc-

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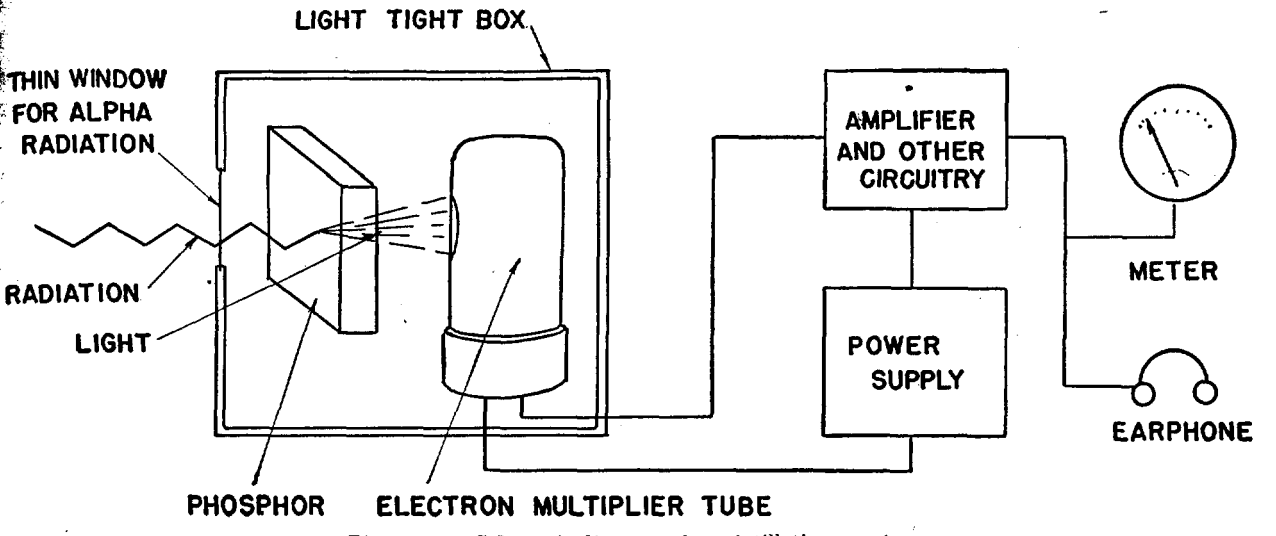

Figure 31. Schematic diagram of a scintillation counter.

Radiation striking the phosphor releases light which is picked up in the electron multiplier tube and is subsequently transformed into a meter reading or earphone indication.

tion with ionization chambers. Satisfactory photoelectric tubes require in the neighborhood of 100 volts per stage and with 10 or more stages this presents the same high voltage problem discussed in conjunction with Geiger-Mueller counters. Since the photomultiplier tubes are light-sensitive, the tube and crystal must be encased in a light-tight coating.

9.04 Other Possibilities

Several other processes have been examined for their possible use as dosage-indicating devices. Electrets show some promise, but further investigation is necessary before their actual application to dosimetry may be used as a basis for long-range planning.

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Chapter 13

CALIBRATION

A problem which at first appears of little consequence is that of instrument calibration. Actually, this is an extremely serious problem to designers, manufacturers, and to users whether in laboratory or field work. There are two calibrations which must be considered:

a. Spectral sensitivity, and
b. Dosage rate.

The first is a function of the materials, configuration, etc., of which the instrument is made. Military radiac equipment is checked for spectral response by the X-ray section of the National Bureau of Standards, and it is considered that they are not likely to change unless the instruments are damaged or altered. Unfortunately, the instrument evolution has not progressed to the point where one is willing to use them per se without continuous rate calibrations.

If errors, some serious, are to be eliminated from quantitative dose rate measurements, then it is necessary to expose the instruments in substantially the same manner in which they are calibrated. This does not mean that qualitative indications cannot be obtained when an instrument is not calibrated for a specific radiation. In the case of the portable Geiger-Mueller counter the instrument is calibrated for gamma radiation but is satisfactorily used to locate beta surface contamination. An extremely complex beta calibration with rigid use restrictions would be required to make the Geiger-Mueller counting rate a quantitative measure of active material.

Alpha calibrations are done with plutonium or uranium sources at the center of the plane of the external opening of the instrument. As a matter of interest, it can be stated that one gram of pure natural uranium emits a total of 2.5×10^4 alpha particles per second. Considerable effort must be placed in determining the absolute number of disintegrations for any sample to correct for self-absorption and geometry.

Beta calibrations present a more serious problem than do alpha, primarily because of scattering effects and absorption of the beta particles. A good number of standards are made by depositing on a foil a known amount of uranium oxide (U_3O_8). The foil having a density of 25 mg/cm^2 will absorb all alpha particles and only about five percent of the beta particles. Strontium 90 is also used as a beta calibration source. It should be noted that the methods of alpha and beta calibrations are not entirely satisfactory and that work is under way to develop better means of calibration.

Radium encased in platinum and cobalt 60 are used as gamma radiation sources for calibration. Sources are calibrated at the National Bureau of Standards at periodic intervals. Information from the source calibrations allows a calculation of intensity at one centimeter from the source. Intensities at other distances are found by use of the inverse square law.

In the case of radium, the following relationship exists:

$$I_{Ra}=\frac{8.4m}{d^2}$$

where I is the dose rate in roentgens per hour at a distance d centimeters from a source of mass m milligrams. The half life* of radium being relatively long (1,600 years), there is little worry about changes in source weight over periods of months. Cobalt 60, on the other hand, has a half life of 5.3 years, and it is therefore necessary to include the elapsed time t in days from the date of source calibration. The radioactive cobalt is produced artifically in a rod of ordinary cobalt metal through neutron irradiation in an atomic pile. A number of atoms within the rod will not become radioactive; therefore, the weight of the sample is not necessarily indicative of the radioactivity. As a result, the source activity A in millicuries** giving a numerical quantity of dis-

*The half life of a radioisotope is the time required to lose half of its activity.

**Millicurie = 1/1000 curie. The curie is generally accepted as that quantity of substance which decays at the rate of 3.7×10^{10} disintegrations per second. The millicurie (mc) has a disintegration rate of 3.7×10^7 disintegrations per second.

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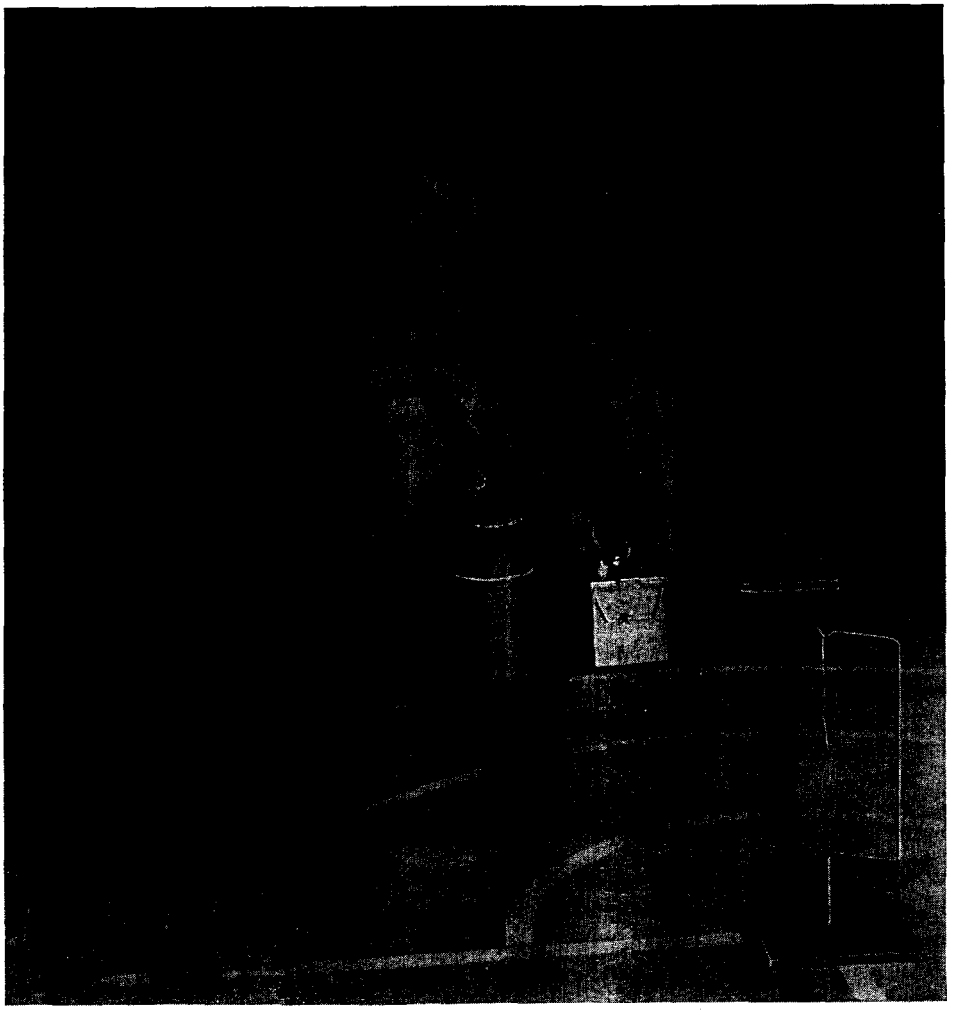

Figure 39. Gamma calibration.

Three ionization chamber survey meters are calibrated against a cobalt 60 source.

integrations per second at the time t must be given. The calibration relationships for Co^{60} are:

$$I_{Co^{60}} = \frac{8.4A \cdot e^{-\frac{0.693 \times t}{5.3 \times 365}}}{d^2} = \frac{8.4A \cdot e^{-3.58 \times 10^{-4} t}}{d^2}$$

An open area usually is marked off into concentric circles with the source of radiation placed at the center as shown in figure 39. Such an arrangement can be used for the rapid calibration of large numbers of medium level dose rate instruments. Instruments calibrated at extremely high levels, such as 100 to 500 roentgens per hour, require remote control devices to move the instrument and make adjustments in order to minimize personnel exposure.

It should be noted that geometrical considerations limit the maximum intensity which can be obtained from a single source. This closest approach of the instrument to the source at which it can be considered that the square law still holds and at which the detector is receiving a uniform radiation may be taken as equal to 10 times the maximum dimension of the detector.

The gamma calibration of film badges, dosimeters, and other dosage reading is accomplished in a manner similar to that explained above for intensity meters except that the time of exposure at a given intensity must be measured carefully.

46
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TABLE III.—*Use of various radiac instruments*

Instrument	Purpose	Radiation			Use	Remarks
		Alpha	Beta	Gamma		
Pocket dosimeter	Individual exposure	------	------	X	Field or laboratory	High cost compared to pocket chamber. Requires separate charger.
Drift meter	Rate of exposure	X	X	X	Secondary standard in conjunction with laboratory.	
Pocket chamber	Individual exposure	------	------	X	Field or laboratory	Requires a separate charger-reader.
Thin window chamber	Rate of exposure	X	X	X	In conjunction with laboratory.	Many problems involved with thin windows.
Chamber survey	Rate of exposure	------	------	X	Field or laboratory	Use for high dose rate radiation measurement.
Proportional counter	Disintegration rate	X	------	------	In conjunction with laboratory.	Many problems involved with thin windows.
Geiger counter	Rate of exposure	------	X	X	Field or laboratory	Limited to detection and low dose rate.
Scaling circuit	Cumulative record	X	X	X	Laboratory	
Count rate meter	Rate of exposure	X	X	X	Laboratory	
Scintillation counter	Rate of exposure	X	X	X		
Film badge	Individual exposure	------	X	X	Field or laboratory	Teriffic problems involved with development in any quantity. Gives a permanent record.
Track plates	Degree of contamination	X	------	------	Laboratory	
Color crystals and liquids, chemicals, photo conductive crystals, etc.	Individual exposure	------	------	X		
Electrets	Individual exposure	X	X	X		

One of the reasons for the high beta-gamma activity immediately following an atomic bomb explosion is the short half-life elements either produced as fission products or as the result of neutron irradiation. This high activity results in the rapid decay and rapid removal of the beta-gamma hazard. In the case of an air burst, depending on height and many other variables, the area beneath the blast may be safe from an emergency military beta-gamma standpoint, within less than an hour after the burst. This is not the case if alpha emitters remain after a bomb explosion. These will not show high initial activity and will not decay immediately to a point of no concern but may remain for years to plague occupants of a contaminated area. Being alpha and not active in enormous quantities, they may be overlooked because of the difficulty of detection, and perhaps through their introduction into foods, water, ventilating systems, etc., may present a definite hazard to a long term military organization.

To give indications of possible military usage, instruments will be discussed in conjunction with each type of radiation.

14.02 The Alpha Particle

Because of the very short range and penetrating power, alpha particles are very difficult to measure. A 5 Mev alpha particle has a range of only 3.5 centimeters in air; therefore, the maximum distance a detector with an air window can be

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Figure 44. Helicopter ground monitor.

The Geiger counter is used for an air check of ground gamma contamination.

Figure 45. Decontamination.

The portable Geiger-Mueller detector will be a primary instrument for use in equipment decontamination.

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Chapter 15

DESCRIPTION OF ACTUAL INSTRUMENTS

15.01 The Field in General

It is desired to give a detailed description of the physical properties of commercial and military instruments which are making their way throughout the Defense Establishment. In addition, some instruments which are perhaps obsolete or of no military value have been so widely discussed that they will be included to show their relation to other such equipments. Laboratory instruments are not discussed and personnel interested in these equipments are invited to examine Reference (10). For security reasons, a good number of instruments which were developed under the Manhattan District had code names. Also, some commercial model numbers have come into use. An effort is made here to correlate these names and numbers with the types of instruments we have been discussing.

The writer may not be familiar with all instruments which have been produced and are being produced; therefore, inclusion or omission of a specific manufacturer's equipment is not necessarily to be construed as either condemnation or praise. Indications will be made as to whether an instrument is obsolete, etc. The following code will be used: *"o"*—obsolete; *"i"*—in present military use; *"f"*—anticipated for future military use. A tabulation of instruments of interest is given in Appendix I.

The great majority of the instruments described herein are unclassified. Usually there will be no classification on any instruments issued for general use.

15.02 Pocket Dosimeters and Pocket Chambers

	Pocket dosimeters	Pocket chambers
Radiation detected	Gamma	Gamma.
Full scale ranges	100 mr, 200 mr, 10 r, 50 r, 100 r	100 mr, 200 mr, 100 r,
Detector	Ionization chamber	Ionization chamber.
Volume of chamber	2.5 cc	5 cc (less with high range).
Indicator	Image of electroscope fiber on calibrated reticle of microscope.	Separate reader.
Weight	1 oz	1 oz.
Shape	Size of fountain pen	Size of fountain pen.
Dimensions	½ in. diameter, 4—4¾ in. long	½–⅝ in. diameter 4½—5½ in. long.

A. Pocket Dosimeters

Manufacturer	JAN Number	Mfg. model Number	AEC Number	Full scale reading*	Distinguishing color
A. O. Beckman Company (*f*)	IM–50/PD		PIC–10A	200 mr	Silver.
				200 mr	Black.
Cambridge Instrument Company (*i*).	IM–51/PD	BM 17400	PIC–9A	200 mr	Grey.
Kelley-Koett - Manufacturing Company (*i*).	IM–9/PD (Set AN/PDR–3).	K–100	PIC–7A	200 mr	Black.
		K–109	PIC–7A1	200 mr	Black.
		K–110	PIC–7A2	200 mr	Black.
	IM–9A/PD	K–111	PIC–7A3	200 mr	Black.
	IM–19/PD	K–150 (*o*), 151 (*i*)	PIC–7B	10 r	Blue.
	IM–20/PD	K–160 (*o*), 161 (*i*)	PIC–7C	50 r	Red.
		K–170 (*o*), 171	PIC–7D	100 r	Purple.
Landsverk (*o*)	IM–9( )/PD (Set AN/PDR–3( )).	L–200	PIC–7A	200 mr	Silver.

*A number of 100 mr dosimeters have been manufactured for use within Atomic Energy Commission laboratories.

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B. Military Portable Geiger-Mueller Detectors

-number	a. AN/PDR-8 (*f*) b. AN/PDR-8A (*f*) c. AN/PDR-8B (*f*) d. AN/PDR-8C (*f*)	AN/PDR-15 (*f*)	AN/PDR-27 (*i*)	AN/PDR-T-2 (*i*).
ufacturer	a. Hoffman b. R. C. A. c. Hoffman d. Admiral		General Electric	El-Tronics (model PR-2).
iation	Beta-gamma	Beta-gamma	Beta-gamma	Beta-gamma.
ranges (mr/hr)	a. Calibrated in r/24 hr. b, c, d. 0–0.5, 0–5.0, 0–50, 0–500 (beta indication on first two scales).	0–0.5, 0–5.0, 0–50, 0–500 (beta indication on first two scales).	0–0.5, 0–5.0, 0–50, 0–500 (beta indication on first two scales).	0–0.5, 0–5.0, 0–50.
ector	BS–1; halogen-filled mica end window (first two scales). BS–2, low sensitivity halogen tube (3rd and 4th scale).	BS–1; halogen-filled mica end window (first two scales). BS–2, low sensitivity halogen tube (3rd and 4th scale).	BS–1; halogen-filled mica end window (first two scales). BS–2, low sensitivity halogen tube (3rd and 4th scale).	RCL MK–1 Mdl 21.
ta window (mg/cm²).	3–4	3–4	3–4	30.
indow area (in.²)	0.44	0.44	0.44	8 openings ½ in. x 1 7/16 in.
dicator	Meter plus headphones	Meter plus headphones.	Meter plus headphones.	Meter plus headphones.
robe dimensions	8 x 1⅜ x 1⅜ in	7¾ x 1⅜ x in. dia	8 x 1⅜ x 1⅜ in	8⅝ x ⅞ in. dia.
ength of probe cable.	60 in	60 in	60 in	36 in.
orm factor	Kidney-shape	Rectangular "flat iron"	Rectangular	Rectangular.
imensions (length x width x height in inches).	10 x 6½ x 7	11¼ x 4⅜ x 3½	9¼ x 5 5/16 x 4½	10 x 6 x 7.
eight (pounds)	a. 14.1 b. 11.5 c. 12.8 d. 11.5	11	10.2	9.5.
ower supply	a. Electronic vibrator b. Vibrator(sub-miniature tubes). c. Neon oscillator d. Vibrator (sub-miniature tubes).	Electronic vibrator	Neon oscillator (plug in electronic unit).	3–300 v batteries.

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*A more complete bibliography will be found in Nucleonics I, 68 (December 1947). Other bibliography and references which may be of interest to the reader can be found appended to Reference (9).

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Appendix I

A-N NOMENCLATURE LIST

The following table lists A-N numbers for equipments now in field use or anticipated for use in the near future. It should be noted that this is far from a complete listing.

Nomenclature	Instrument	AEC No.	Manufacturer	Model	Trade or code name
AN/ADR-1	Airborne gamma dose rate.				
AN/ADR-2	Airborne dosimeter.				
AN/PDR-2	Ion chamber group dosimeter.	MIC-4A	Victoreen	300	Proteximeter
AN/PDR-3:					
IM-9/PD	Pocket dosimeter	PIC-7A	Kelley Koett	K-100	
IM-9A/PD	Pocket dosimeter		Kelley Koett	K-110	
PP-311A/PD	Charger	AV-2D	Kelley Koett	K-135	
PP-354B/PD	Charger		Kelley Koett		
AN/PDR-4:					
DT-16/PD	Pocket chamber	PIC-2C	Victoreen	352	
DT-16A/PD	Pocket chamber	PIC-1B	Nuclear Instrument and Chemical Co.	3340	
PP-316/PD	Charger-reader	AE-2A	Victoreen	287	Minometer.
AN/PDR-5:					
(IM-1A/PD)	Portable G-M detector	SGM-2B	Victoreen	263A	
AN/PDR-7:					
(IM-8( )/PD)	Portable G-M detector	SGM-4B	Nuclear Instrument and Chemical Co.	2610	
AN/PDR-8	Portable G-M detector		Hoffman		
AN/PDR-8A	Kidney shaped G-M		Radio Corporation of America.		
AN/PDR-8B	Portable G-M detector		Hoffman		
AN/PDR-8C	Portable G-M detector		Admiral		
AN/PDR-9	Beta-gamma ion chamber.	SIC-4A	Argonne National Laboratory.	C2M10	Betty Snoop.
AN/PDR-10	Portable alpha proportional counter.		General Electric		Poppy.
AN/PDR-11	Alpha scintillation counter.		Radio Corp. of America		
AN/PDR-15	Portable G-M detector				
AN/PDR-18	Gamma scintillation counter.				
AN/PDR-20	Beta-gamma descriminating chamber.		General Electric		Zeus.
AN/PDR-21:					
DT-35( )/PD	Pocket chamber	PIC-2E	Kelley Koett	K-700	
PP-43( )/PD	Charger-reader	AE-1B	Kelley Koett	K-425	
AN/PDR-26	Portable G-M detector	SGM-18A	El-Tronics	SM3	
AN/PDR-27*	Portable G-M detector		General Electric		
AN/PDR-T-1	Ion chamber survey	SIC-18A	Kelley Koett	K-350	
AN/PDR-T-2	Portable G-M detector		El-Tronics	PR-2	
AN/UDR-3	Hand and foot monitor	CGM-17B	Kelley Koett	K-240	
AN/UDR-10	Hand and foot monitor	CGM-T4A	Radio Corp. of America	EMA-2B	

*The AN/PDR-27 was once known as the AN/PPR-8E.

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Nomenclature	Instrument	AEC No.	Manufacturer	Model, name	Trade or code name
AN/USQ–1	Gamma telemetenug				
IM–3/PD	Ion chamber survey	SIC–9B	Victoreen	247A	
IM–4/PD	Alpha-beta-gamma ion chamber.	SIC–2A	Victoreen	356	Zeuto.
IM–5/PD	Beta-gamma ion chamber	SIC–7A	Sylvania	RD–316	Cutie pie.
		SIC–7B	Tracer Lab	SU–1A	Cutie pie.
IM–7A/PD	Drift meter	SIC–5A	Kelley Koett	K–320	
IM–39/PD	Portable G-M detector	SGM–15A	National Technical Laboratories.	MX–5	
IM–40/PD	Ion chamber survey	SIC–15A	National Technical Laboratories.	MX–6	
IM–50/PD	Pocket dosimeter	PIC–10A	A. O. Beckman Co		
IM–51/PD	Pocket dosimeter	PIC–9A	Cambridge Instrument Co.	BM 17400	
PP–354A/PD	Dosimeter charger		Chatham Electronics		
PP–527/PD	Dosimeter charger	AV–7A	Cambridge Instrument Co.		

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APPENDIX II

GLOSSARY OF TERMS CONCERNED WITH RADIAC INSTRUMENTS

Avalanche.... The action within proportional and Geiger counters in which one ion (electron) produces another ion by collision, these two ions (electrons) producing still further ionization.

Background... The background count is that which is caused by any agency whatever other than the radiation which it is desired to detect. For health protection, it usually includes the radiations produced by naturally occurring radioactivity and cosmic rays.

Calibration... The process of checking and adjusting instrument operation against known sources of radioactivity.

Chamber..... A container in which ionization is allowed to take place and in which all the original ions are collected—otherwise known as an *ion chamber*.

Count..... A terminated discharge produced by an ionizing event in a counter tube.

Counter..... A device, such as a proportional counter or a Geiger-Mueller counter, which responds to or counts individual ionizing events.

Count rate meter. The instrument used to indicate the rate of counts indicated by a counting chamber or a proportional or Geiger counter. It may be used with both portable and laboratory equipment.

Curie..... The curie is a standard measure of the rate of radioactive decay equal to 3.7×10^{10} disintegrations per second.

Dead time.... The time interval between individual counts in which a counter is insensitive.

Densitometer.. Electronic-Optical device used to determine the density (blackening) of film badges.

Dosimeter..... An individual dosage indicating device—more specifically, a direct reading quartz fibre electroscope sensitive to gamma radiation and about the size of a fountain pen. Otherwise known as a pocket dosimeter, a pocket electroscope, or a quartz fibre dosimeter.

Electrometer tube. A specially constructed vacuum tube used for the amplification of minute currents such as those obtained from ionization chambers.

Film badge.... A small packet containing photographic film which is used to obtain individual radiation dosage readings. Readings are primarily of gamma radiation.

Geiger counter. A low dose rate, high sensitivity detector of beta and gamma radiations. It may be either a light-weight portable detector or a laboratory instrument. Also known as a Geiger-Mueller counter.

Geiger region.. The part of the characteristic curve of pulse size as a function of voltage in which the size of the pulse is independent of the magnitude and type of radiation producing the initial ionizing event.

Half life..... The time required for the disintegration of a radio-isotope to one-half of its initial rate of activity.

1263478

Ionization---- The process by which a neutral atom or molecule loses an electron with the remaining ion becoming positively charged and the electron and positive ion forming an *ion pair.*

Ionization chamber survey meter. A high dose rate, low sensitivity instrument for the measurement of gamma radiation—also known as a gamma survey meter or an ion chamber.

Photographic dosimetry. The entire operation required to obtain individual dosage records by the use of film badges. This includes calibration, film development, densitometry, etc.

Plateau------ The roughly horizontal part of the counting rate as a function of voltage curve in which there is very little change in count rate with change in voltage.

Pocket chamber. A non-self-reading individual gamma dosage indicating device about the size of a fountain pen.

Proportional counter. An instrument which counts alpha particles and descriminates against counts produced by beta and gamma radiations. It may be either a portable or a laboratory instrument.

Proportional region. The portion of the characteristic curve of pulse size as a function of voltage in which the size of the pulse is proportional to the number of ions formed by the initial ionizing event.

Quenching---- The process of extinguishing the action within a Geiger counter tube. External quenching utilizes an electronic circuit. A self-quench is produced by action within the counter tube.

Recombination. The process of union between electrons and positive ions to form neutral atoms or molecules—the opposite of ionization.

Recovery time. The time interval after recording a count before the pulses produced by the next ionizing event in the counter are of substantially full size.

Region of continous discharge. The part of the characteristic curve of pulse size as a function of voltage in voltages higher than those of the Geiger region. In this region the tube goes into a state of continuous discharge.

Region of limited proportionability. The part of the characteristic curve of pulse size as a function of voltage in which the gas amplification depends both upon the numbers of ions produced in the initial event and upon the voltage (very little use).

Roentgen----- For military purposes, this is a unit of dosage for the measurement of gamma radiation. This is the quantity of radiation which, under standard conditions, produces 2.08 x 10^9 ion pairs per cc of air.

Scaler------- A laboratory electronic device used to record the number of pulses from a counter. An electronic circuit capable of dividing the incoming pulse rate by a constant factor so that mechanical methods of recording the pulse may be used.

Threshold----- In the Geiger counter characteristic curve there are two thresholds: (a) The voltage below which no pulses are recorded is the characteristic curve threshold, and (b) the voltage at which the plateau starts is known as the threshold of the Geiger region.

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